The University of Edinburgh
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DISSERTATION

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Title: The influence of visual secondary tasks on prospective memory in healthy adults

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ABSTRACT

Prospective Memory can be defined as "remembering to carry out intended actions at an appropriate point in the future" (McDaniels & Einstein, 2007). Prospective Memory tasks have been shown to be susceptible to interference with Working Memory tasks (Benuzzi, Basso & Nichelli, 2005), indicating Working Memory involvement in their execution. Following up on evidence of Phonological Loop involvement (Law, Logie & Pearson, 2006), this study aims to determine if the Working Memory involvement is restricted to verbal Working Memory, or if visuo-spatial memory content would demand resources of the visuo-spatial sketchpad (Baddeley & Logie, 1999). N=19 participants completed the Edinburgh Virtual Errands Task (EVET) with measures of Prospective Memory performance being collected, while being presented with either a visuo-spatial or nonsense Working Memory task, Brooks' (1967) Matrix Path Test (MPT). Contrary to my original hypotheses, analysis showed no significant difference in performance change in EVET performance, as well as MPT performance between the visuo-spatial group and the nonsense group, although there was a trend to be observed in the data towards a larger impairment in spatial groups.

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1. Theory

1.1. Definition of Prospective Memory

A common definition of prospective memory (*PM*) was given by McDaniel and Einstein (2007) as "remembering to carry out intended actions at an appropriate point in the future", which is to say the encoding of intentions to execute actions and the retrieval thereof make up prospective memory.

Within the taxonomy of memory, PM content can therefore theoretically be of any kind. An additional dimension is needed to distinguish between time-based and event-based PM (Guimond, Braun, & Rouleau, 2008). Time-based PM is used when an action as part of a plan has to be executed after or at a certain time, whereas event-based PM occurs when a certain action has to be executed directly before or after another action.

We use PM all the time in everyday settings, whether it be remembering to pick up the dry-cleaning or putting a certain ingredient in the frying pan at the right time. Whenever there is a need to plan a series of actions and execute them in some order, we use PM.

Given its importance, PM would seem to be an obvious element of memory to investigate. However, most of the research has taken place over the last two decades. In fact, as late as 1985 there had been no more than 10 experimental studies on PM (McDaniel & Einstein, 2007). Since, however, the number of studies has risen significantly (Marsh, Cook, & Hicks, 2006) and questions about the validity of the idea of PM, that had not been raised as with many barely researched constructs (Crowder, 1996), have been addressed in detail (Salthouse, Berish, & Siedlecki, 2004).

1.2. Methods in Prospective Memory Research

1.2.1 Examining Prospective Memory in Standard Laboratory Tasks

A typical PM paradigm typically consists of a task (referred to as "PM task") to be executed after a certain stimulus (event-based paradigm) or amount of time (time-based paradigm), and an ongoing task that is executed throughout the experiment to keep participants busy up to the right moment to execute the task (McDaniel & Einstein, 2007). In most cases the ongoing task will be so designed that it is demanding enough to keep subjects from verbally rehearsing the original task, or some kind of distraction is added.

1.2.2 Examining Prospective Memory in Virtual Environments

There have been a few studies investigating PM in virtual environments (Knight & Titov, 2009; Logie, Law, Trawley, & Nissan, 2010). Virtual environments make it easy to implement ongoing tasks as well as PM tasks to be executed at the same time, both time-based and event-based.

As Knight and Titov (2009) showed, studies conducted in virtual environments can assess PM not only in healthy subjects, but even in patient groups effectively.

1.3. What Do We Know About Prospective Memory?

1.3.1 Neurological Correlates of Prospective Memory

Neurological studies of PM have found activation specific to planning goals in the posterior parietal cortex (Lindner, Iyer, Kagan, & Andersen, 2010), as well as posterior regions of the prefrontal cortex (Haynes et al., 2007). These activation patterns seem to differ from those of pure goal representation, and are in fact are specific to future goals (Genovesio, Brasted, & Wise, 2006). There is also evidence that the planning and execution of a goal take place in distinct areas of the brain (Haynes et al., 2007), specifically providing further support for the notion of brain regions in the posterior parietal cortex and posterior PFC specific to PM mechanisms.

1.3.2 Prospective Memory in Clinical Samples

Most of the research on PM has been conducted in samples of clinical patients or of potentially impaired subjects like elderly people (Masumoto, Nishimura, Tabuchi, & Fujita, 2011; Wang et al., 2010). As such, most of it has focussed on which samples show impaired PM performance.

It has been shown that especially patients with Schizophrenia (Wang et al., 2008) and Alzheimer's Dementia or Mild Cognitive Impairment (Smith, Della Sala, Logie, & Maylor, 2000; Thompson, Henry, Rendell, Withall, & Brodaty, 2010) tend to display weak performance in PM tasks. In both cases, this deficit is in fact specific to PM, i.e. remains significant even after controlling for other cognitive deficits. Consequently, PM has been thought of as a potential diagnostic measure for early Alzheimer's screening, as well as a possible endophenotype of Schizophrenia. Research has also been conducted in patients with autism spectrum disorder (Altgassen, Schmitz-Hübsch, & Kliegel, 2010), where no impairment for patients has been found, despite reported difficulties on prospective memory functioning in real life settings.

1.3.3 Prospective Memory in Healthy Subjects

Research in healthy subjects has found relatively stable individual differences in PM performance (Cuttler & Graf, 2007; Mäntylä, 2003) between subjects, with evidence linking it to certain aspects of personality, most notably conscientiousness and neuroticism (Cuttler & Graf, 2007). It has also been shown that in healthy subjects, experimental data of these individual differences seem to be a better predictor of everyday ratings of PM performance than in clinical samples (Altgassen et al., 2010), emphasising the validity of PM as a psychological construct.

With regard to differences between tasks, it has been found that the workload in the ongoing task is the single strongest predictor of performance (Stone, Dismukes, & Remington, 2001), with delay between making and executing intentions being, perhaps surprisingly, non-significant, at least in the range between 1 and 5 minutes. Stone et al. (2001) also found that the performance in PM while a routine ongoing task was done differed significantly from when an ongoing task deviating from routine patterns was done, emphasising the importance of the kind of ongoing task.

The PM task, however, is not only influenced by the ongoing task, it also influences it (Jäger & Kliegel, 2008; McDaniel & Einstein, 2007). Jäger and Kliegel (2008) called this half of the mutual effect the *interference effect* and found it to be greater in event-based PM tasks than in time-based ones. Einstein et al. (2005) found that the effect is smaller in ongoing tasks that require quicker responses and hypothesised that this may be a product of subjects employing unnecessary and obstructive control processes if they have the time (Einstein et al., 2005), a phenomenon that had been known in working memory tasks (Reitman, 1974).

1.3.4 Prospective Memory and Multitasking

Multitasking, in this study defined as executing multiple tasks without being able to execute them simultaneously or sequentially (Law, Logie, & Pearson, 2006) and PM are not the same. However, they are often required in the same tasks, and conceptually refer to similar things: Both require the interleaving of different tasks and rely heavily on goal activation to work (Verbruggen, Schneider, & Logan, 2008), but PM may involve pausing between tasks

McDaniels and Einstein (2007) as opposed to tasks following in rapid succession like in multitasking (Bowman, Levine, Waite, & Gendron, 2010).

Arguably, many experiments of PM require participants to multitask (Benuzzi, Basso, & Nichelli, 2005; Guimond et al., 2008; Logie et al., 2010), thus making it essential to be aware of features of human multitasking when researching PM. While additional phenomena may occur, if multitasking is part of the prospective memory task, these multitasking phenomena will influence the results of studies on PM.

1.3.5 Prospective Memory and Working Memory

The assumption that ongoing tasks and/or distractions should serve the purpose of preventing subjects from verbally rehearsing their planned actions (McDaniel & Einstein, 2007) makes it apparent that there likely is a connection between working memory and PM performance. The fact that there is a well-established connection between working memory abilities and multitasking (Colom, Martinez-Molina, Shih, & Santacreu, 2010), which is used in most PM tasks, provides further support for this idea.

And in fact the connection has been largely confirmed in research over the years, as working memory performance is a strong predictor, possibly the strongest predictor, of PM performance (Logie & Maylor, 2009; Marsh & Kicks, 1998; West & Bowry, 2005). It has been hypothesised that this is because prospective memory relies on working memory processes (Marsh & Hicks, 1998), which would seem plausible with findings like those of Stone et al. (2001) that workload has the biggest impact on PM performance, given the limitations of working memory capacity (Danemann & Merikle, 1996) as well as findings that PM mistakes often occurs because the subject fails to engage in prospective cues (West, Carlson, & Cohen, 2007), which could be interpreted as a failure of the executive functions of working memory.

With working memory often divided into visual and auditory working memory (Baddeley & Logie, 1999), there is also evidence of different effects of different modalities on PM (Benuzzi et al., 2005; Gathercole, Briscoe, Thorn, & Tiffany, 2008; Uttl, 2006), which I will now describe in greater detail.

1.3.6 Prospective Memory and Visual Working Memory

With the established connection between PM and working memory as well as research showing the different effects of modally different tasks on PM performance, this raises the question of whether these different effects are caused by a possible modality-specificity of prospective memory tasks, by differences in cognitive demands of ongoing tasks, or if PM in general makes use of modality-specific working memory resources.

Benuzzi et al. (2005) found visual working memory tasks to interfere with a very general time-based PM task (temporal production), which would eliminate modality-specificity of prospective memory tasks as the only explanation for the differential effects of modalities. This is not to say that PM tasks are not modality specific as one could make a compelling case that they are, but to say that there has to be something else to PM to explain the observed phenomena.

To give a concrete example, (Law et al., 2006) examined the effects of auditory secondary tasks on multitasking, using measures of PM and found significant impairment of performance with aurally demanding secondary tasks, as well as a stronger impairment by tasks that also employed executive functioning. This was interpreted as involvement of the phonological loop and central executive as proposed by Baddeley & Logie (1999) (Law et al., 2006).

With this in mind and results showing that visual working memory tasks can have an influence on some PM tasks (Benuzzi et al., 2005), I want to investigate whether this finding can be reproduced in more typical and event-based PM tasks. This should give a hint of a possible involvement of the visuo-spatial sketchpad (Baddeley & Logie, 1999) in PM processes involving visuo-spatial material.

1.3.7 This Study and Prospective Memory

This study combines an event-based PM task with an ongoing visual working memory task. The ongoing working memory task is the aural presentation of Brooks' Matrix Path Test (Brooks, 1967), which can be presented in one of two versions: One is a spatial task presented aurally, the other one, called the nonsense condition, is a purely verbal task. The comparison of these two conditions allows for an analysis purely of impact of visuo-spatial features of an ongoing task, since they are identical in every other aspect, most notably Brooks (1967) found them to be identical in workload.

The paradigm requires the subjects to answer quickly, thus I do not expect a big interference effect of the prospective memory task on the ongoing task (McDaniel & Einstein, 2007) – however, performance in the ongoing task will be analysed as well and compared between conditions, as is not unusual in secondary task paradigms (Logie, Cocchini, Della Sala, & Baddeley, 2004), so if an interference effect does occur, this will be analysed as well.

1.4. Research Question

This study is designed to shed light on the working memory demands of prospective memory. Specifically, I pose the question if visuo-spatial working memory resources are in demand during prospective memory tasks that comprise visuo-spatial aspects. The documented effects of visual working memory tasks on prospective memory could be explained by their general cognitive demand, since studies finding this effect were more interested in effects of short-term memory demand or working memory demand in general than modality specificity (e.g. Benuzzi et al. (2005); Gathercole et al., 2008). This would still allow for the possibility that prospective memory content is stored purely verbally.

The idea of this study is to compare healthy adults' prospective memory performance while faced with visuo-spatial working memory tasks and their performance during equally demanding non-visuo-spatial working memory tasks.

To achieve this, participants were asked to complete Brooks' Matrix Path Test (MPT) (Brooks, 1967) as well as the Edinburgh Virtual Errand Task (Logie, Law, Trawley, & Nissan, 2010), a PM-task in a virtual environment that requires participants to remember and execute a series of errands in a virtual building. Since remembering a path through a virtual building would be considered visuo-spatially demanding, if indeed PM can be stored visuo-spatially, it is likely that this would be the case in EVET tasks. EVET scores have also been shown to be significantly predicted by visual WM ability (Logie et al., 2010). Both MPT versions were presented aurally, thus making it impossible to remember EVET errands by verbal rehearsal, which could have resulted in a ceiling effect that would make it impossible to examine the nature of the PM storing.

Participants completed both the MPT and the EVET first individually and then combined, with the central measures being the drop in performance from the single-task conditions to the dual-task condition.

A drop in PM performance specifically with visuo-spatial secondary tasks would provide evidence that when the task has strong visuo-spatial features, PM content is stored visuo-spatially. Conversely, not finding a specific effect of visuo-spatial secondary tasks would speak for the notion that PM is stored verbally even in strongly visuo-spatial tasks.

1.5. Hypotheses

Without stating the specific hypotheses in terms of specific dependent measures, the general assumptions of this study are twofold:

1.5.1 Hypothesis 1

EVET performance is going to be more impaired by *spatial* MPTs as secondary tasks than by *nonsense* MPTs as secondary tasks, i.e. the difference between the participants' performance in the single task EVET and the dual task EVET, is going to be bigger in the *spatial* condition.

1.5.2 Hypothesis 2

MPT performance when the MPT is the secondary task, i.e. when it is performed during the EVET, is going to be more impaired in the *spatial* MPT than in the *nonsense* MPT.

Both these hypotheses stem from the same theoretical reasoning. If prospective memory can have visuo-spatial properties and uses the visuo-spatial sketchpad (Baddeley & Logie, 1999), then in an environment like the EVET where planning a route would have visuo-spatial properties, a visuo-spatial secondary task would interfere more with having to perform prospective memory tasks, leading both to reduced PM performance and an interference effect in the ongoing task (Jäger & Kliegel, 2008).

This does not a priori mean that both performance measures have to be affected. Participants could, however, completely neglect one task and concentrate on the other if the tasks indeed share the same resources (Baddeley & Logie, 1999). Since neither task was presented to the participants as the more important one, an effect in both tasks is to be expected.

2. Methods

To answer the question if visuo-spatial WM resources are in fact used during potentially visuo-spatial prospective memory tasks, a group of N=21 participants was asked to perform the EVET as a measure of prospective memory, as well as Brooks' MPT as a secondary task, in the spatial version or in the nonsense version, depending on the condition. Having participants do both MPT versions was a means to ensure that any effects would not be due to the general cognitive demand, since more difficult secondary tasks tend to influence working memory capacity more negatively (Turner & Engle, 1989).

2.1 Participants

The initial sample consisted of N=21 voluntary unpaid participants between 22 and 29, mean age M=23.7, SD= 1.8. 16 participants were female, 5 were male. All participants had at least an undergraduate degree from university. Two participants' data had to be eliminated due to technical problems with the data recording. The following analysis were done on the remaining sample of 19 participants, age M=23.5, SD=1.8, 15 female and 4 male.

2.2 Material

The experiments were run on a Dell Dimension 5100 PC with dual-core 3.40GHz Intel CPU, 1GB RAM and 256MB ATi graphics card. The monitor was a 24'' flat screen monitor running at 1280*1024 pixels, 32 bit and 60Hz. Participants were seated approximately 60cm in front of the monitor.

2.2.1 Brooks' Matrix Path Test

The matrix path test (MPT) by Brooks (1967) is a simple way of aurally presenting WM tasks that can be either visuo-spatial or nonsensical. It works as follows:

The participant hears the description of a matrix and is instructed to repeat back, verbatim, as accurately as possible, what he or she just heard. The matrix is rectangular, consisting of 16 squares, 8 of which contain numbers. Number 1 is always in the same square, with 2 being in an adjacent square, 3 being in a square adjacent to 2 and so forth. Examples of such matrices can be seen in figure 1 and figure 2. The descriptions are delivered in a format as described in table 1 with a path through the matrix described using the directions "up", "down", "to the right" and "to the left". The numbers are spoken at a rate slightly faster than 2 seconds per number.

In nonsense matrices, there were no directions, as instead of directions participants were given nonsense descriptions for where to put the numbers: "to the good", "to the bad", "to the quick" and "to the slow". A sample nonsense matrix is given in table 1.

In this experiment, there was a break of 30 seconds between each matrix, giving the participants enough time to repeat the directions.

Table 1: MPT instructions

Spatial	*Nonsense*
In the starting square put a 1.	In the starting square put a 1.
In the next square to the right put a 2.	In the next square to the quick put a 2.
In the next square up put a 3.	In the next square to the good put a 3.
In the next square to the right put a 4.	In the next square to the quick put a 4.
In the next square down put a 5.	In the next square to the bad put a 5.
In the next square down put a 6.	In the next square to the bad put a 6.
In the next square to the left put a 7.	In the next square to the slow put a 7.
In the next square down put an 8.	In the next square to the bad put an 8.

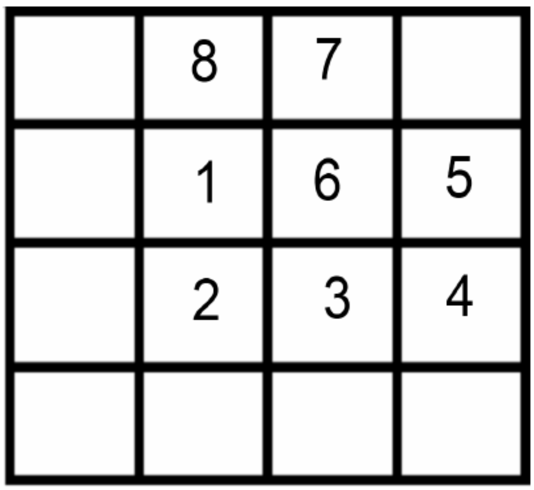

Figure 1: Spatial Matrix

2.2.1.1 Scoring Since there are always 8 numbers and number 1 is always in the same square, there are 7 directions per matrix that the participant has to remember. Therefore I used the total number of correct directions divided by 7 as the score for each participant for each matrix.

2.2.1.2 Usefulness of the MPT Brooks showed that an aurally presented spatial MPT interferes with spatial WM tasks, while an aurally presented nonsense MPT does not significantly interfere with them (although there is always a slight effect of active listening on visual WM (Gherri & Eimer, 2011)). This is despite the fact that participants are at no point asked to visualise spatial matrices. Consequently, the spatial MPT should demand resources of the visuo-spatial sketchpad, while the nonsense MPT should be about equally cognitively demanding, only without the visuo-spatial component. For this reason, aurally presented MPTs (spatial and nonsense) were chosen as secondary tasks to the EVET in the dual-task condition.

2.2.2 The Edinburgh Virtual Errands Task (EVET)

The Edinburgh Virtual Errands Test (EVET) was developed by the Human Cognitive Neuroscience group at the University of Edinburgh and used in previous studies by members of the department (Logie, Trawley & Law, 2010; Trawley et al., 2011). The logic of the EVET is the same as the logic of the Multiple Errands Test by Shallice and Burgess (Shallice & Burgess, 1991). Participants are asked to do a certain set of tasks under some time pressure, with experimenters monitoring the number of tasks completed correctly.

2.2.2.1 Implementation The EVET was developed using the Hammer Editor by Valve. Hammer is used to create levels for the first- person 3-D computer game Half-Life 2, the EVET being such a level.

The EVET environment is a model of the inside of a four-storey building consisting of a concourse with 5 rooms on the left and 5 rooms on the right on each floor, as well as a set of stairs on each side connecting the floors. Rooms were named using a letter for the floor they were on (G for ground floor, F for first, S for second, T for third) and a number from 1 to 10, so e.g. the third room on the second floor would be named S3. These room names are visible next to every door. Rooms of the same number are always in the same location on each floor. A screenshot of the EVET can be viewed in figure 3. At the top of the screen, the time elapsed during the experiment is displayed.

Participants move around the EVET using the “w” and “s” keys to move forward and back, as well as the “e” key to interact with objects and the mouse to change direction and camera perspective. Participants’ positions were recorded in a log file at a rate of 10Hz, along with action commands to interact with objects.

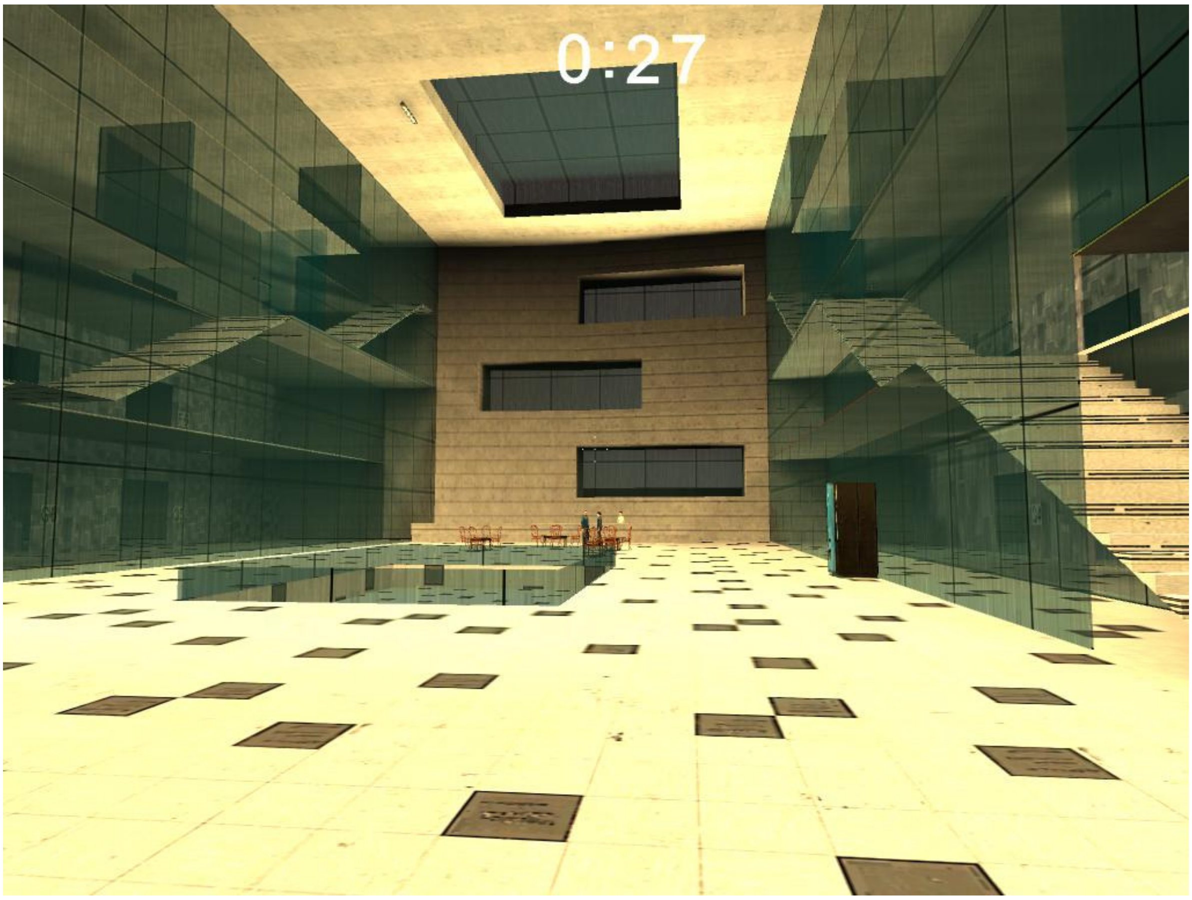

Figure 2 – View of EVET: Concourse

2.2.2.2 Errands Each participant in this study was given a list consisting of 8 errands, 3 of which were split up in two parts. The precise list of errands can be viewed in table 2. The errands are already in an optimal order. Participants knew this but were allowed to do the errands a different order unless specified otherwise. The last errand was open-ended. The number of folders sorted counted towards the total score, as did the number of total errands completed. Points were subtracted for non-errand rooms entered, building rules broken and times not met for tasks number 5 and 10.

There was a rule in the building that the stairs on the right side of the concourse should only be used to go up, while the stairs on the left should only be used to go down. It was possible to break this rule, but each time counted as a mistake in the total EVET score. Participants were informed about this rule and the consequence of breaking it during the practice phase and reminded of it if they broke it during practice.

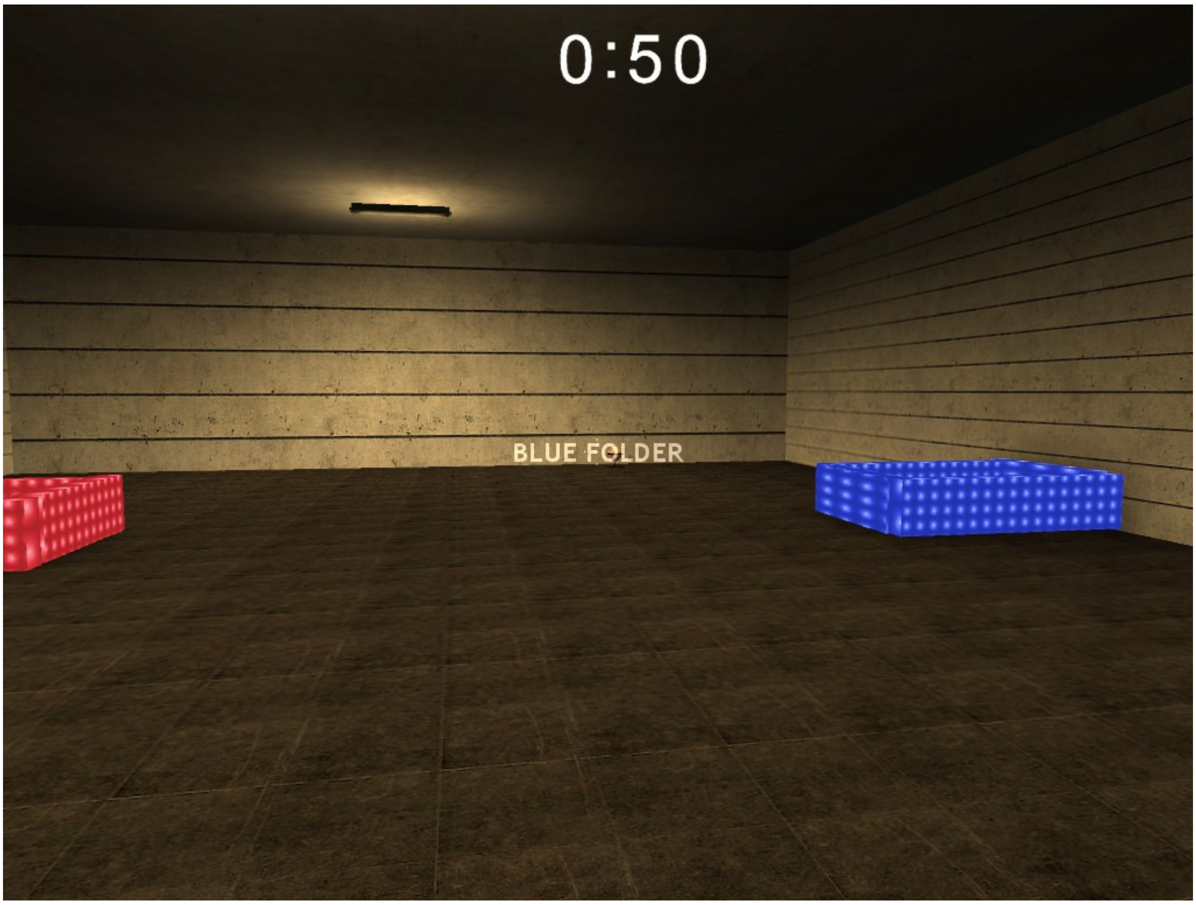

Figure 3: View of EVET: Task 11

Table 2: Errands to do in EVET

START GROUND FLOOR
(1) Get stair code in G8 from notice board
(2) Turn off lift on G-Floor
(3) Pick up newspaper for your boss in G3
<you must complete tasks 1-3 before leaving 1st floor>
(4) Drop newspaper off on boss' desk in S4
(5) Meet person in S10 before 3:00 minutes
(6) Get key card from table in F9
(7) Pick up brown package in T4
(8) Use key card to unlock G6 (via G5)
(9) Drop brown package in G6
(10) Turn on cinema in S7 at 5:30 minutes
(11) Sort red and blue binders in room S2

The errands were to be completed within a time limit of 8 minutes, except for the last errand that could not be completed since it was open-ended. After 8 minutes, the experimenter would halt the EVET, regardless of how many errands had been completed. The participants were made aware of this right before the EVET started.

2.2.2.3 PM in EVET The EVET demands participants to both encode and execute a plan to complete all errands in time, hence including both aspects of PM. It also includes both time-based and event-based PM tasks, since some tasks have to be done in order, others by a certain time. Within the typical PM-task paradigm, navigating through the EVET environment serves as the ongoing task while remembering the next task to do is the PM task.

2.2.2.4 Calculating EVET scores EVET scores are calculated using the following measures (in brackets how many points they were adding or subtracting): *1* Errand completed (+1), *2* binders sorted (+0.5), *3* wrong item picked up (-0.5), *4* wrong room entered (-0.5), *5* stair rule broken (-0.5), *6* times not kept for time-based errands number 4 and 10.

2.3 Procedure

Participants each went through one experimental session that took roughly an hour. One participant at a time was tested. The experimental sessions began with an introduction, informing participants about the goal and nature of the study, as well as matters of ethics and confidentiality. Every participant then went through a practice phase, in which they were introduced to the EVET environment. This included completing 5 errands, while an experimenter explained the details of the EVET environment. Since the purpose of this phase was to familiarise participants with the EVET environment and not to examine PM, the active errand was at all time displayed at the top of the screen. The practice session ended when the fifth errand was completed and took between 4 minutes and 8 minutes, depending on each participant.

After the practice session, participants entered the test phase, which took around 45 minutes. The test phase consisted of participants completing a practice MPT, a single-task MPT, a single-task EVET and an EVET/MPT dual-task. The order of the tasks as well as the type of the MPTs varied.

2.3.1 Groups

A between-subject design was used in the study, as participants were divided into groups that were asked to complete different types of tasks, and in a different order. The study did not include a control group, as each participant completed control tasks.

Half of the participants completed the spatial MPT, half of them completed the nonsense MPT. Additionally, half the participants completed the single-task EVET first, while the other half completed the dual-task EVET/MPT first. This resulted in 4 different groups: (1) Spatial, single-task first, (2) spatial, dual-task first, (3) nonsense, single-task first and (4) nonsense, dual-task first.

2.3.2 Sequence of Tasks in Test Phases

The detailed sequence of events is shown in table 3, displaying different versions of the experiment in different columns.

2.3.2.1 Single-Task First In single-task first groups (groups 1 and 3), participants first completed the single-task EVET. To do this, they were given a list of 8 errands (3 of which were split up in two parts), which they were asked to memorise. They were given the list for 2 minutes, followed by a free recall of any errands they remembered, without help from the experimenter. They were then given the list for another 5 minutes, followed by another recall phase, in which the experimenter corrected them or gave cues, if necessary. They then completed the 8-minute EVET.

The single-task EVET was then followed by a short MPT practice, consisting of a short explanation of the task by the experimenter, then two practice matrices that participants were asked to repeat. After this, participants were asked to do an 8-minute MPT, consisting of 10 matrices that were to be repeated. The practice matrices and the test matrices were of the same type (spatial or nonsense), depending on the group of each participant.

Finally, participants were given the list of errands again to look at it until they felt comfortable with it, but for a maximum of two minutes, and completed the EVET/MPT dual-task.

2.3.2.2 Dual-Task First In dual-task first groups (groups 2 and 4), participants were first asked to complete two practice MPTs, with the MPT type depending on the group. They then completed an 8-minute test MPT of the same type. Next they learned the errand list by the same pattern as the single-task first groups, in two phases of 2 and 5 minutes plus recall, respectively. They would then do the EVET/MPT dual-task with the same type of MPT as in the previous MPT phase.

Finally, after completing the dual-task, they were given the list of errands again for as long as they felt they needed to be comfortable with it, but for a maximum of 2 minutes, and complete the single-task EVET.

Table 3 – Sequence of Events

<table>
<tr><td colspan="4">1. Introduction: Inform participants about audio recording, confidentiality, what to expect</td></tr>
<tr><td colspan="4">2. EVET practice</td></tr>
<tr><td colspan="4">3. Test Phase</td></tr>
<tr><td colspan="2">EVET first:</td><td colspan="2">MPT first:</td></tr>
<tr><td colspan="2">Plain EVET</td><td>Spatial MPT</td><td>Nonsense MPT</td></tr>
<tr><td>Spatial MPT</td><td>Nonsense MPT</td><td>EVET with spatial secondary task</td><td>EVET with nonsense secondary task</td></tr>
<tr><td>EVET with spatial secondary task</td><td>EVET with nonsense secondary task</td><td colspan="2">Plain EVET</td></tr>
</table>

2.4 Data and Data Analysis

2.4.1 Dependent Variables

There were two main dependent variables: (1) *EVET performance* – a score based on tasks completed, folders sorted, times met and mistakes made was calculated for the single-task EVET and the dual-task EVET. (2) *MPT performance* - the ratio of correctly repeated directions within the matrices was measured for both the single-task MPT as well as for the MPT in the dual-task.

For both the EVET performance and the MPT performance, a drop-off from single-task to dual-task condition was expected.

Change in performance from single-task to dual-task was calculated in standard deviations of the single-task performance. To do this, the mean and standard deviation of single-task MPT scores and EVET scores were calculated for each condition. Then each participant's difference between single-task and dual-task performance was calculated and divided by the standard deviation of the single-task group. The results of this was a measure of how many standard deviations worse (or better) each participant was in the dual-task condition than in the single-task condition (*t-statistics*). These t-scores were the basis for subsequent analyses.

Average scores in nonsense MPTs were expected to be lower than in spatial MPTs, as Luck and Vogel (1997) showed that visual WM stores objects as integrated objects with fewer chunks of information than in a simple list of the same number of attributes like a nonsense MPT presents (Luck & Vogel, 1997).

2.4.2 Other Data collected

Aside from demographic data and the dependent variables, several more EVET variables were collected. These included the simple EVET score, i.e. simply the number of errands completed, times violating the stair rule, wrong rooms entered, wrong objects picked up, as well as folders sorted and the times at which the time-based errands were completed.

2.4.3 Hypotheses

Two main hypotheses were posed:

Hypothesis 1: EVET performance drops more in the spatial dual-task condition than in the nonsense dual-task condition.

In terms of dependent variables, this means that the average t-scores for dual-task EVET performance (calculated with the mean and standard deviation of the single-task EVET scores) were expected to be lower in the spatial condition than in the nonsense condition. These t-scores were used because the most relevant statistic was the difference between the skill base-line (i.e. single-task performance) and performance under dual-task conditions.

Hypothesis 2: MPT performance drops more in the spatial dual-task condition than in the nonsense dual-task condition.

In terms of dependent variables, this means that the average t-scores for dual-task MPT performance (calculated with the mean and standard deviation of the single-task MPT scores) were expected to be lower in the spatial condition than in the nonsense condition. These t-scores were used because the most relevant statistic was the difference between the skill base-line (i.e. single-task performance) and performance under dual-task conditions.

2.4.4 Analysis of Data

The data from the MPTs and the EVET were analysed using a 2x2 ANOVA. There were two between-subjects factors: *MPT type* (spatial or nonsense) and *sequence* of tasks (single-task EVET first or dual-task EVET/MPT first). The t-scores of MPT and EVET under the dual-task condition were the dependent variables. The model was fitted using the *lm* function of the statistics package R.

3. Results

3.1 EVET results

On average, participants in the spatial groups performed worse in the dual-task EVET than in the single-task EVET (difference: M=-.39*SD), while there was hardly any difference between the two EVET scores in the nonsense groups (difference: M=.09*SD). Both of these differences were non-significant.

Participants predictably performed better in the second EVET (M=7.89, SD=4.69) than in the first EVET (M=2.68, SD=4.62). EVET scores by group and phase are illustrated in figure 3. A 2*2 ANOVA with the factors *MPT type* and *sequence* revealed that there was no significant difference in drop-off from single-task EVET to dual-task EVET between spatial and nonsense groups ($F(1, 15)=1.784$, $p=.201$), i.e. there was no significant main effect of the factor *MPT type* on t-scores with the drop-off being non-significantly bigger in the spatial condition.

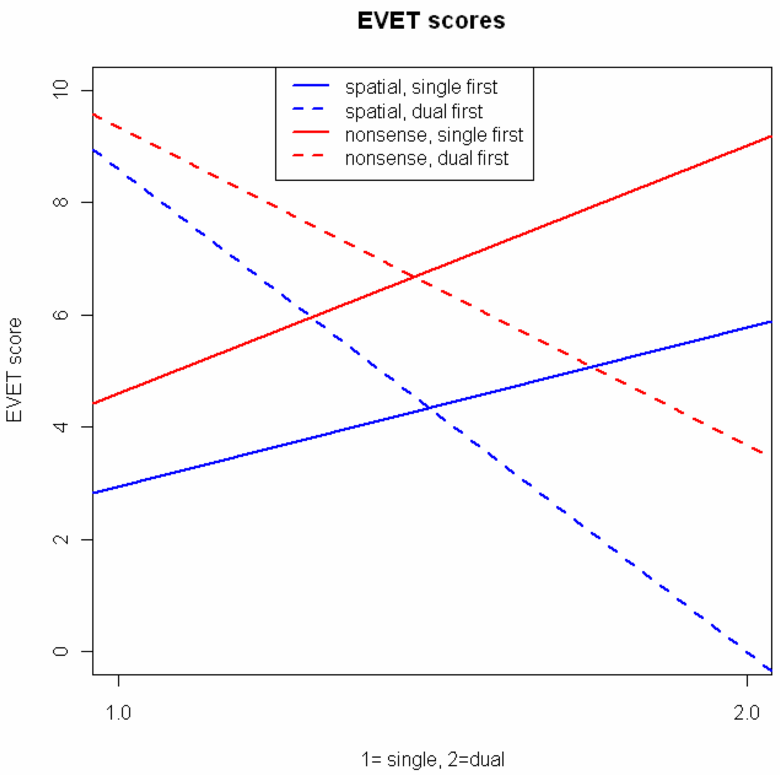

Figure 4 – EVET Scores

There was a significant main effect of *sequence* ($F(1, 15)=6.884$, $p=.019$), which means that the drop-off from single-task EVET to dual-task EVET was significantly larger in groups where the dual-task was completed first (M=-.76, SD=.72) than in groups where the single-task EVET was completed first (M=.23, SD=.81).

There was not significant interaction between the two factors ($F(1, 15)=.007$, $p=.936$).

The mean EVET results for single-task EVET and dual-task EVET for all groups are shown in table 4. Note that since mistakes count against the overall score, it is very possible to achieve a negative score.

Table 4 – Mean EVET Scores by Group

Group	*EVET single*	*EVET dual*
Spatial; single first	2.83	5.67
Spatial; dual first	8.60	0
Nonsense; single first	4.60	9.00
Nonsense; dual first	9.33	3.67

The factors *MPT type* and *sequence* combined explain 24% of the variance (adjusted R-squared = .239). EVET results for the differences between single-task and dual-task are shown in figure 5.

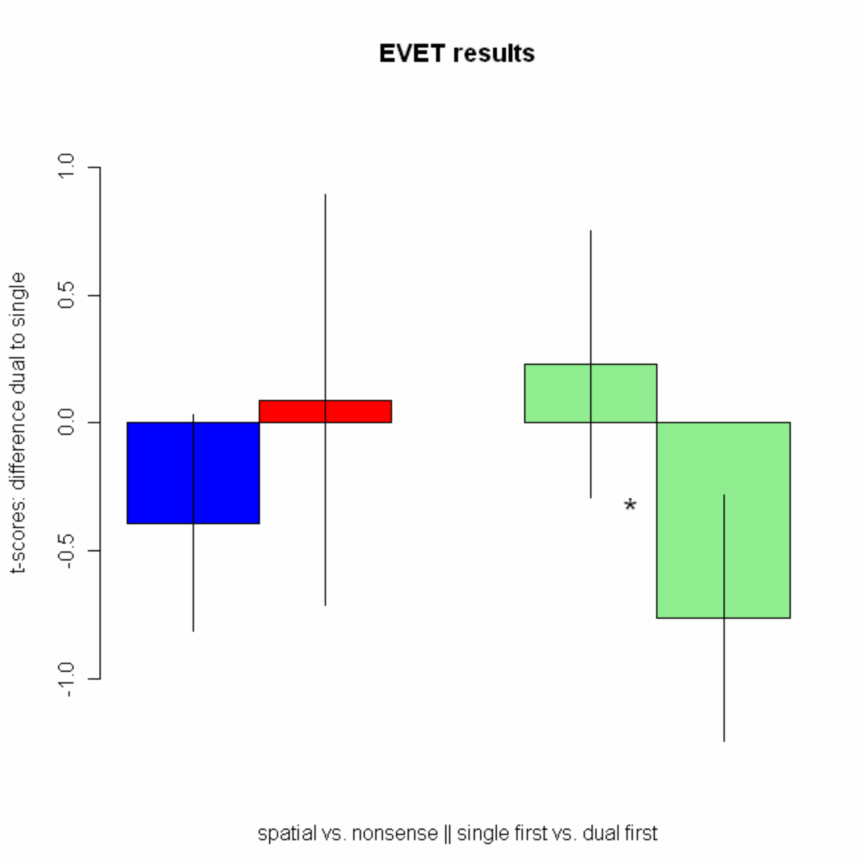

Figure 5 – EVET Results (t-scores) - Error Bars: 2*SE

3.2 MPT results

Raw MPT scores by group and phase are displayed in figure 5. A 2*2 ANOVA on t-scores for the drop-off from single-task MPT to dual-task MPT with the factors *MPT type* and *sequence* revealed no significant main effect of the factor *MPT type* ($F(1, 16)=4.355$, $p=.053$), although it did approach significance. This means the mean drop-off in the spatial condition (M=4.71*SD) was barely non-significantly larger than the drop-off in the nonsense condition (M=3.09*SD).

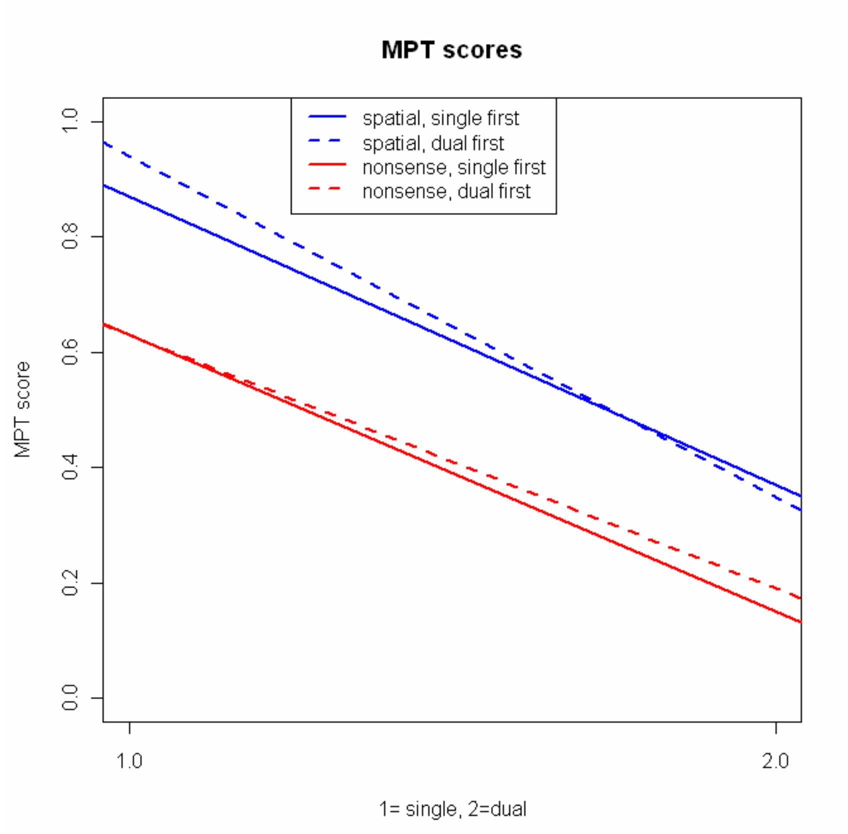

Figure 6 – MPT Scores

There was no significant main effect for the factor *sequence* ($F(1, 16)=.004$, $p=.951$), which means the drop-off from single-task MPT to dual-task MPT did not differ by sequence.

There was no significant interaction between the two factors ($F(1, 16)=.066$, $p=.799$).

On average, participants in the spatial condition (M=.63, SD=.33) performed better than in the nonsense condition (M=.40, SD=.27). The mean MPT scores for all conditions are shown in table 5.

Table 5 – Mean MPT Scores by Group

Group	*MPT single*	*MPT dual*
Spatial; single first	.87	.37
Spatial; dual first	.94	.35
Nonsense; single first	.63	.15
Nonsense; dual first	.63	.19

The factors *MPT type* and *sequence* combined explain 7% of the variance (adjusted R-squared = .069). MPT results for the differences between single-task and dual-task are shown in figure 7.

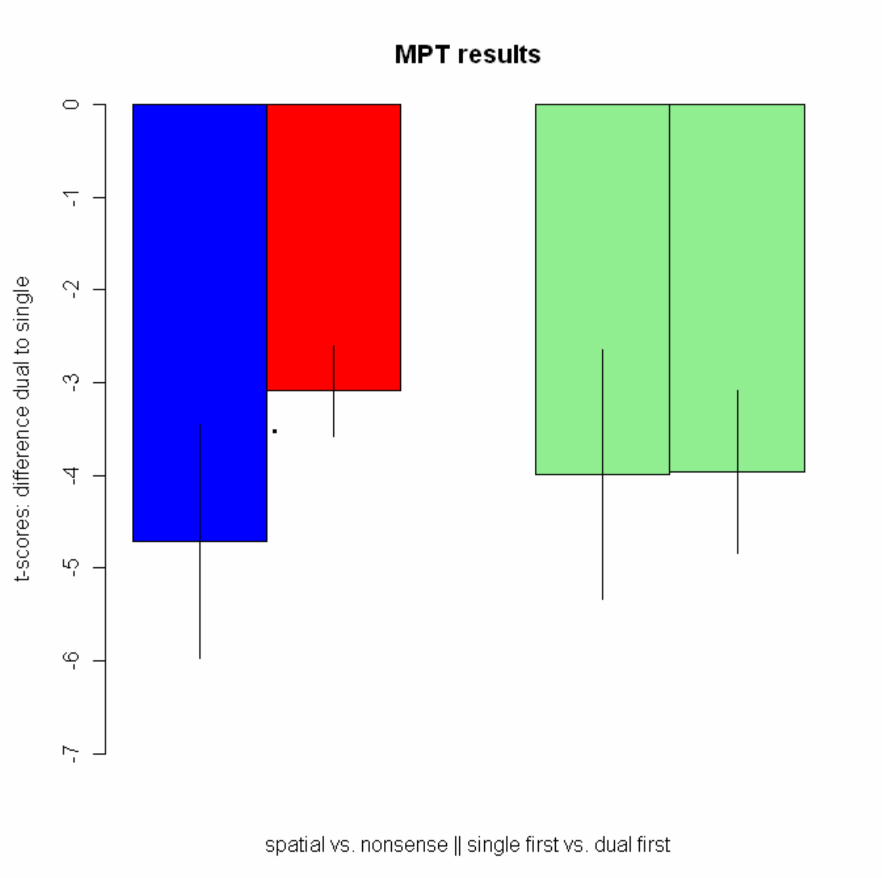

Figure 7 – MPT Results (t-scores) - Error Bars: 2*SE

3.3 Other Results

Subjects scored lower on average on the dual-task EVET (M=4.7, SD=5.1) than on the single-task EVET (M=5.8, SD=5.5), but not significantly lower (*t*(36)=.638, *p*=.527). They scored lower on dual-task MPTs (M=.27, SD=.21) than on single-task MPTs (M=.78, SD=.19) ($t(36)=7.95$, $p<.001$).

3.3.1 Simple EVET Scores

The simple EVET scores were measured and analysed in the same manner as the final EVET scores. The difference between scores in the dual-task EVET was taken and expressed in standard deviations difference from the scores in the single-task EVET. The pattern was the same, as participants' performance dropped more in the spatial groups (M=-.46*SD, SD=.81) than in the nonsense groups (M=.33*SD, SD=.96).

A 2*2 ANOVA, factors *MPT type* and *sequence*, analogous to the ANOVA used for final EVET scores, revealed a main effect for the factor *sequence* ($F(1, 15)=8.673$, $p=.010$), as in the analysis for the final scores, but also for *MPT type* ($F(1, 15)=5.259$, $p=.037$), unlike the analysis for the final EVET scores. The t-scores are visualised in figure 8.

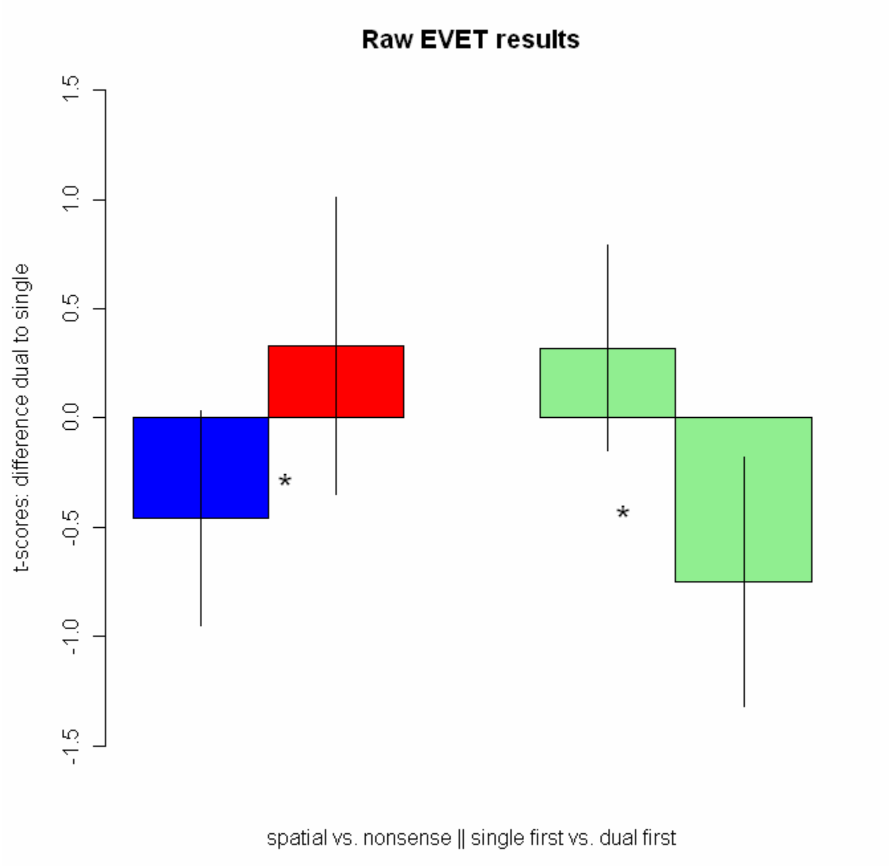

Figure 8 – Raw EVET Results (t-scores) - Error Bars: 2*SE

This model explained 38% of the variance in simple EVET t-scores (adjusted r-squared = .38).

On average, participants completed M=6.2 errands in the single-task condition and M=5.7 errands in the dual-task condition, with 9 out of 19 participants achieving a perfect 8 in the single-task EVET and 6 out of 19 achieving an 8 in the dual-task EVET (5 of which achieved an 8 in both conditions).

3.3.2 Miscellaneous Measures

In the MPT data, 28% of directions were left out by participants in the spatial dual task condition, and 52% in the nonsense dual-task condition.

There was a non-significant negative correlation between MPT performance in the dual-task condition and t-score for the dual-task EVET of r=-.13.

There was also a non-significant correlation between gender and dual-task EVET performance of r=.30, as women scored slightly better.

4. Discussion

4.1 Discussion of Hypotheses

Hypothesis 1 proposed that the difference from single-task EVET scores to dual-task EVET scores would be significantly bigger in spatial MPT conditions than in nonsense MPT conditions. This hypothesis could not be confirmed with the dependent variable used. The mean difference was in fact bigger in the spatial condition, but this result was not statistically significant or even approached significance ($F(1, 15)=1.784$, p=.201).

Hypothesis 2 proposed that the difference from single-task MPT scores to dual-task MPT scores would be significantly bigger in spatial MPT conditions than in nonsense MPT conditions. This hypothesis could not be confirmed either. The mean difference was bigger in spatial conditions, but although it did approach significance ($F(1, 15)=4.355$, p=.053), it was not statistically significant.

These two results make it hard to argue for an involvement of the visuo-spatial sketchpad in PM, as an effect of MPT type would have been the most important result: The main hypothesis was based on the idea that both the spatial MPT and the EVET rely on resources of the visuo-spatial sketchpad, hence a drop-off in performance between single-task and dual-task in both MPT and EVET would have been expected to be bigger in the spatial condition, and significantly so.

It may serve as an explanation for this that EVET scores do not appear to differ too much between single-task and dual-task (M_{dual}=4.7 vs. M_{single}=5.8, $t(36)=.638$, $p=.527$). This is despite there being a huge difference in MPT. The obvious explanation would be that the MPT is simply more susceptible to interference than the EVET. If mistakes occur due to too high demand to the limited WM resources, performance in the pure WM task would be more likely to suffer significantly. Also, as Jäger and Kliegel (2008) showed, the interference effect of the PM task on the ongoing task is stronger with event-based PM tasks, of which there were a lot more in this study than time-based tasks. Still, the lack of a significant difference from single-task conditions to dual-task conditions raises the question how resilient to interruptions PM is in general. Statistical significance aside, it would seem plausible that in a laboratory setting that clearly emphasises the PM aspect of an experiment, the variations would be smaller than in other tasks, especially if PM content does not test the limits of memory capacity as much as it tests how much attention is paid to a future task. It may be useful to examine the average drop-off in PM performance in previous studies examining the influence of different ongoing tasks on PM. Due to the large number of MPT answers not given, however, it also appears quite likely that participants prioritised in favour of the EVET and simply ignored the MPT when answering threatened to impede their EVET performance, which may be supported by the fact that fewer answers were given (48%) in the nonsense MPT than in the spatial MPT (72%), as participants struggled more in the nonsense MPT in dual-task as well as single-task conditions. This view may be supported by the fact that there was only a small negative correlation between EVET performance and MPT performance in dual-task conditions (r=-.136, *n.s.*). If both tasks had been approached with the same commitment, one would have expected there to be at least a slight positive correlation, since in this case differences in the drop-off would have to be caused mainly by individual differences in visual WM capacity. Of course, both tasks being approached with exactly the same commitment is a very high standard to begin with, still the amount of answers left out was unexpectedly high.

Another explanation for the lack of results in EVET scores may be in the design of the experiments, i.e. in the nature of virtual environments and the material and procedure of this particular study. Participants tend to vary in their skill in navigating through virtual environments (Waller, 2000), contributing to the very large EVET score variance observed in this study. This effect, however, is quite small according to Waller (2000), and even with the knowledge of such an effect, accounting for it would be difficult, and additional practice unlikely to make up for the difference.

4.2 Discussion of Other Results

It is important to note that this study was designed to explore the possibility of visuo-spatial sketchpad involvement in prospective memory tasks, and hence the possibility of visuo-spatial prospective memory content encoded in such a modality, as opposed to purely verbalised. Consequently, the material was not chosen for the purpose of being as generalisable as possible, but to detect possible effects. While these were not found in the main dependent variables, there was plenty of evidence to be found in other variables measured.

Regardless of group, the mean EVET score of the second run (M=7.895, SD=4.689) was always higher than that of the first (M=2.684, SD=4.619). This was not surprising and the strongest effect on EVET scores, indicating that practice had the strongest effect on performance. The significant main effect for *sequence* on the single-task – dual-task difference can be attributed to this, as participants performed better on the dual-task EVETs in the second run than on single-task EVETs in the first run. This means that participants benefited so much from the additional practice that the change in performance was in fact positive in single-task first groups. This effect did not occur in the MPT scores, as sequence had almost no influence on the performance difference ($F(1, 15)=.012$, $p=.951$). This is hardly surprising seeing that the MPT is a rather simple WM task that is unlikely to benefit a lot from additional practice. Another effect that was expected was that single-task EVET scores (M=5.842, SD=5.530) were higher than dual-task EVET scores (M=4,737, SD=5.141), which was almost a prerequisite for the paradigm, since the search for a specific impairment would have been futile had there been no impairment at all. This of course does not necessarily imply anything about statistical significance, as groups may (and did) differ in the amount of impairment observed.

Most interesting were perhaps the results to be found in the analysis of simple EVET scores: Since a 2*2 ANOVA of differences between single-task scores and dual-task scores revealed a significant main effect for *MPT type* ($F(1, 15)=5.259$, $p=.037$), this presents a difficult call.

One has to be careful not to overstate the importance of one single measure that was not the dependent variable in the first place, but the fact that every single measure from MPT scores to final EVET scores to simple EVET scores shows a tendency towards a higher interference in the spatial condition, this makes it hard to dismiss the notion that there could be an involvement of the visuo-spatial sketchpad in PM tasks involving visuo-spatial material. The effect found in simple EVET scores is merely the strongest hint that such an involvement may exist. It should be noted that while there was a significant difference between spatial MPT groups and nonsense MPT groups in the simple scores, none of these differed significantly from the single-task EVET. As noted above, the main hypothesis was for these groups to differfrom one another, although it is curious that not even the spatial group (i.e. the significantly more impaired group) differed significantly. This speaks for the notion that the relatively small difference in EVET scores was due to subjects focussing on completing EVET errands at the expense of MPT. Since it has been shown that participants' PM performance drops when they are involved in WM tasks, or even just random word production tasks (Law, Logie & Pearson, 2006) and that workload has a very direct effect on PM performance (Stone et al. 2001), not engaging in these tasks is the only way to explain the very strong performance of participants in dual-task EVET. This is especially true in nonsense groups, as workload does seem to be high judging from the fact that few participants did not make mistakes even in the single-task condition MPTs. This would not only explain the smaller-than-expected effect of the dual-task condition, but also the fact that MPT type had a smaller effect than expected: If participants try too hard not to engage WM resources when there could be an interference, there will not be a large difference in interference between MPT types.

The difference between the simple EVET scores and the final EVET scores can be attributed to the effect of mistakes made, since this is what was added to the calculation to compute final scores. The reason for using final EVET scores over simple EVET scores was that due to previous studies' results a ceiling effect was expected, leading to little variance in the simple EVET scores for young, healthy participants. This effect did in fact occur, with 15 out of 38 data points reaching the maximum score of 8. However, while adding the mistakes and folders sorted made to the analysis increased the standard deviation of EVET scores from 2.02/1.95 for single task / dual-task scores to 5.53/5.14, an ANOVA revealed no significant main effect of *MPT type* on mistakes made ($F(1, 15)=1.231$, $p=.285$). There was a highly significant main effect for *sequence* ($F(1, 15)= 24.881$, $p<.001$), indicating that a lot more mistakes were made in the first run through EVET. In other words, except for the finding that more mistakes were made in the first run, without the additional practice, the additional variance was not systematic and hence not helpful in finding any kind of effect. Interestingly, there was no significant difference between the weighed sum of mistakes made in dual-task conditions and single-task conditions (M_{dual}=-.368, M_{single}=-.947, $t(36)=.455$, $p=.652$). This would mean that the main reason for the large number of mistakes made was not necessarily the difficulty of the tasks, but rather a lack of familiarity with EVET, despite every participant completing a practice session right before the test phase.

This is a little disheartening for the results of this study, as it indicates that EVET mistakes, which conmprised a large part of the variation in EVET scores, were not caused by any experimental manipulation but rather a latent function of the experimental design that proved to be more problematic for the EVET data than the slight ceiling effect found in the simple EVET scores.

It is not clear how to interpret the different findings in simple and final EVET scores with regard to visuo-spatial sketchpad involvement in prospective memory. The fact that it is always possible to correct mistakes, with the cost of it depending on when a mistake is discovered, may make the simple EVET score a rather coarse measure of PM. The final score is more is probably more sensitive to smaller lapses. This makes it seem more useful, but from a theoretical standpoint it could be argued that for prospective memory as a construct, small lapses are only useful to the degree that they predict bigger mistakes. In practice at least, an "appropriate point in the future" (McDaniel & Einstein, 2007) when an action is supposed to be remembered, will rarely be confined by a second or two.

4.3 Possible Criticism

Choosing the final EVET scores as the dependent variable proved to be a problem in this study and one of the more obvious criticisms. Since the added variance was essentially not much else than random noise, it made any statistical analysis extremely problematic and interpretation of the results difficult.

There would be multiple ways to go about this in future similar studies: One option would be to eliminate counting mistakes from the analysis. If the simple EVET score proves to be more predictive of results in other studies, then it might be useful to use it. From a theoretical standpoint, it would seem that some mistakes (picking up wrong objects, entering wrong rooms) are already captured in the simple score purely because they would make it harder to finish all errands in time, so there might be some double-dipping. This is not true, of course, for breaking the stair rule and sorting folders.

Another way would be to increase the amount of practice every participant is getting before the test phase. This may be helpful for mainly because the average final EVET score is higher than the simple EVET score in the second EVET run (i.e. more influenced by sorting folders, thus fulfilling the role of removing the ceiling effect – mean difference MD=1.369) whereas it is lower in the first EVET run (i.e. more influenced by mistakes, thus not solving the ceiling effect problem while introducing more variance in the lower, already well-differentiated, scoring regions – mean difference MD=-2.684). Additionally, if a difference in familiarity with the environment between runs has such an adverse effect on the usefulness of EVET statistics, perhaps it would be advisable to run EVET in a purely between-subject design not involving participants completing multiple EVET runs. This measure could be combined with increasing the amount of practice.

Another criticism of the study could be the fact that there is no way to force participants to give MPT answers in the dual-task conditions. Since there was not possible to score differently for participants not answering as opposed to participants giving the wrong answer, it may have made a large difference that participants left out 52% of the answers in the nonsense condition, but only 28% in the spatial condition. Even among the answers given, the percentage of correct answers differed (55% in the spatial groups, 33% in the nonsense groups), so there is a decent chance that the number of items guessed at least did not skew the numbers in favour of the spatial groups, but the results are not as clear-cut due to the massive amount of missing data. Also, the difference in how many answers were given may have had an impact on the effect of the factor *MPT type*.

Lastly, there is the issue of sample size. With a sample size that was reduced to 19 after eliminating participants where technical problems occurred, an effect size of .66 would have been needed to achieve a beta-error probability of .05. This means a very strong effect would have been needed to achieve a decent statistical power, and although a large sample size (i.e. .5 or over) could have been expected in a rather straight-forward design like this one, that may have been a strong assumption. Especially in a study that was supposed to explore a possibility that had not been shown before, it would have been advisable to design a study sensitive to possible effects.

4.4 Outlook

The question about whether or not PM is encoded in a modality-specific way could not be answered conclusively in this study and remains open. Despite the possibilities of virtual environments to examine multiple variables at the same time, perhaps a classic straight-forward behavioural experiment could answer such a basic question just as easily, but without the possible difficulties of different skill levels.

Generally, a lot of work in the field of PM has been done either with experts (e.g. Law et al., 2005; Maguire et al., 2003; Spiers & Maguire, 2006) or participants who suffer from dementia or have suffered brain damage (e.g. Huppert & Beardsall, 1993; Zeintl, Kliegel, Rast, & Zimprich, 2006). These studies have typically focussed on what variations in PM can tell us about a certain feature of human behaviour, while not systematically trying to explain how PM works in an average healthy person. Questions like which aspects of memory are involved in the process, and how they interact, could be approached both from a behavioural perspective and a neurological perspective. The latter may be especially well equipped to shed new light on PM. Since most PM paradigms employ some kind of dual-task procedure, there would be plenty of data for neuroimaging studies. The fact that planning processes in PM may not necessarily be made explicit – and it would drastically change the results if they were – makes it an ideal field for neuroimaging research.

5. Conclusion

This study does not provide conclusive evidence for the involvement of visual WM / the visuo-spatial sketchpad in corresponding PM tasks, as several important dependent measures did not differ in a statistically significant way between visuo-spatial and nonsense conditions. However, some of the data supported the idea of such an involvement enough that it should not be dismissed.

The EVET appears to lend itself well to investigating the influences of different manipulations on prospective memory tasks, but needs to be used in a well thought-out way to yield useful results.

6. Appendix

6.1 References

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6.2 Material: List of MPT Trials

6.2.1 Spatial Single-Task

In the starting square put a 1.
In the next square down put a 2.
In the next square to the right put a 3.
In the next square to the right put a 4.
In the next square up put a 5.
In the next square up put a 6.
In the next square to the left put a 7.
In the next square down put an 8.

In the starting square put a 1.
In the next square to the right put a 2.
In the next square to the right put a 3.
In the next square down put a 4.
In the next square down put a 5.
In the next square to the left put a 6.
In the next square to the left put a 7.
In the next square to the left put an 8.

In the starting square put a 1.
In the next square to the right put a 2.
In the next square to the right put a 3.
In the next square down put a 4.
In the next square to the left put a 5.
In the next square to the left put a 6.
In the next square down put a 7.
In the next square to the right put an 8.

In the starting square put a 1.
In the next square to the right put a 2.
In the next square to the right put a 3.
In the next square up put a 4.
In the next square to the left put a 5.
In the next square to the left put a 6.
In the next square to the left put a 7.
In the next square down put an 8.

In the starting square put a 1.
In the next square to the right put a 2.
In the next square to the right put a 3.
In the next square down put a 4.
In the next square down put a 5.
In the next square to the left put a 6.
In the next square up put a 7.
In the next square to the left put an 8.

In the starting square put a 1.
In the next square to the right put a 2.
In the next square to the right put a 3.
In the next square down put a 4.
In the next square to the left put a 5.
In the next square to the left put a 6.
In the next square to the left put a 7.
In the next square down put an 8.

In the starting square put a 1.
In the next square to the right put a 2.
In the next square down put a 3.
In the next square to the right put a 4.
In the next square down put a 5.
In the next square to the left put a 6.
In the next square to the left put a 7.
In the next square up put an 8.

In the starting square put a 1.
In the next square up put a 2.
In the next square to the left put a 3.
In the next square down put a 4.
In the next square down put a 5.
In the next square to the right put a 6.
In the next square to the right put a 7.
In the next square up put an 8.

In the starting square put a 1.
In the next square to the left put a 2.
In the next square up put a 3.
In the next square to the right put a 4.
In the next square to the right put a 5.
In the next square down put a 6.
In the next square down put a 7.
In the next square to the right put an 8.

In the starting square put a 1.
In the next square up put a 2.
In the next square to the right put a 3.
In the next square to the right put a 4.
In the next square down put a 5.
In the next square to the left put a 6.
In the next square down put a 7.
In the next square to the right put an 8.

6.2.2 Spatial Dual-Task

In the starting square put a 1.
In the next square up put a 2.
In the next square to the left put a 3.
In the next square down put a 4.
In the next square down put a 5.
In the next square to the right put a 6.
In the next square to the right put a 7.
In the next square up put an 8.

In the starting square put a 1.
In the next square down put a 2.
In the next square to the left put a 3.
In the next square up put a 4.
In the next square up put a 5.
In the next square to the right put a 6.
In the next square to the right put a 7.
In the next square down put an 8.

In the starting square put a 1.
In the next square to the right put a 2.
In the next square down put a 3.
In the next square to the right put a 4.
In the next square down put a 5.
In the next square to the left put a 6.
In the next square to the left put a 7.
In the next square up put an 8.

In the starting square put a 1.
In the next square down put a 2.
In the next square to the right put a 3.
In the next square to the right put a 4.
In the next square up put a 5.
In the next square up put a 6.
In the next square to the left put a 7.
In the next square to the left put an 8.

In the starting square put a 1.
In the next square to the left put a 2.
In the next square up put a 3.
In the next square to the right put a 4.
In the next square to the right put a 5.
In the next square down put a 6.
In the next square down put a 7.
In the next square to the right put an 8.

In the starting square put a 1.
In the next square up put a 2.
In the next square to the right put a 3.
In the next square down put a 4.
In the next square to the right put a 5.
In the next square down put a 6.
In the next square down put a 7.
In the next square to the left put an 8.

In the starting square put a 1.
In the next square up put a 2.
In the next square to the right put a 3.
In the next square to the right put a 4.
In the next square down put a 5.
In the next square to the left put a 6.
In the next square down put a 7.
In the next square to the right put an 8.

In the starting square put a 1.
In the next square up put a 2.
In the next square to the right put a 3.
In the next square down put a 4.
In the next square down put a 5.
In the next square to the left put a 6.
In the next square to the left put a 7.
In the next square up put an 8.

In the starting square put a 1.
In the next square down put a 2.
In the next square down put a 3.
In the next square to the left put a 4.
In the next square up put a 5.
In the next square up put a 6.
In the next square up put a 7.
In the next square to the right put an 8.

In the starting square put a 1.
In the next square down put a 2.
In the next square down put a 3.
In the next square to the right put a 4.
In the next square up put a 5.
In the next square to the right put a 6.
In the next square up put a 7.
In the next square to the left put an 8.

6.2.3 Nonsense Single-Task

In the starting square put a 1.
In the next square to the quick put a 2.
In the next square to the quick put a 3.
In the next square to the bad put a 4.
In the next square to the bad put a 5.
In the next square to the slow put a 6.
In the next square to the slow put a 7.
In the next square to the slow put an 8.

In the starting square put a 1.
In the next square to the quick put a 2.
In the next square to the quick put a 3.
In the next square to the bad put a 4.
In the next square to the slow put a 5.
In the next square to the slow put a 6.
In the next square to the bad put a 7.
In the next square to the quick put an 8.

In the starting square put a 1.
In the next square to the quick put a 2.
In the next square to the quick put a 3.
In the next square to the good put a 4.
In the next square to the slow put a 5.
In the next square to the slow put a 6.
In the next square to the slow put a 7.
In the next square to the bad put an 8.

In the starting square put a 1.
In the next square to the quick put a 2.
In the next square to the quick put a 3.
In the next square to the bad put a 4.
In the next square to the bad put a 5.
In the next square to the slow put a 6.
In the next square to the good put a 7.
In the next square to the slow put an 8.

In the starting square put a 1.
In the next square to the quick put a 2.
In the next square to the quick put a 3.
In the next square to the bad put a 4.
In the next square to the slow put a 5.
In the next square to the slow put a 6.
In the next square to the slow put a 7.
In the next square to the bad put an 8.

In the starting square put a 1.
In the next square to the quick put a 2.
In the next square to the quick put a 3.
In the next square to the bad put a 4.
In the next square to the slow put a 5.
In the next square to the bad put a 6.
In the next square to the slow put a 7.
In the next square to the good put an 8.

In the starting square put a 1.
In the next square to the good put a 2.
In the next square to the slow put a 3.
In the next square to the bad put a 4.
In the next square to the bad put a 5.
In the next square to the quick put a 6.
In the next square to the bad put a 7.
In the next square to the quick put an 8.

In the starting square put a 1.
In the next square to the bad put a 2.
In the next square to the quick put a 3.
In the next square to the quick put a 4.
In the next square to the good put a 5.
In the next square to the good put a 6.
In the next square to the slow put a 7.
In the next square to the slow put an 8.

In the starting square put a 1.
In the next square to the good put a 2.
In the next square to the quick put a 3.
In the next square to the bad put a 4.
In the next square to the quick put a 5.
In the next square to the bad put a 6.
In the next square to the bad put a 7.
In the next square to the slow put an 8.

In the starting square put a 1.
In the next square to the good put a 2.
In the next square to the quick put a 3.
In the next square to the bad put a 4.
In the next square to the bad put a 5.
In the next square to the slow put a 6.
In the next square to the slow put a 7.
In the next square to the good put an 8.

6.2.4 Nonsense Dual-Task

In the starting square put a 1.
In the next square to the bad put a 2.
In the next square to the slow put a 3.
In the next square to the good put a 4.
In the next square to the good put a 5.
In the next square to the quick put a 6.
In the next square to the quick put a 7.
In the next square to the bad put an 8.

In the starting square put a 1.
In the next square to the quick put a 2.
In the next square to the bad put a 3.
In the next square to the quick put a 4.
In the next square to the bad put a 5.
In the next square to the slow put a 6.
In the next square to the slow put a 7.
In the next square to the good put an 8.

In the starting square put a 1.
In the next square to the bad put a 2.
In the next square to the quick put a 3.
In the next square to the quick put a 4.
In the next square to the good put a 5.
In the next square to the good put a 6.
In the next square to the slow put a 7.
In the next square to the slow put an 8.

In the starting square put a 1.
In the next square to the slow put a 2.
In the next square to the good put a 3.
In the next square to the quick put a 4.
In the next square to the quick put a 5.
In the next square to the bad put a 6.
In the next square to the bad put a 7.
In the next square put an 8.

In the starting square put a 1.
In the next square to the good put a 2.
In the next square to the quick put a 3.
In the next square to the bad put a 4.
In the next square to the quick put a 5.
In the next square to the bad put a 6.
In the next square to the bad put a 7.
In the next square to the slow put an 8.

In the starting square put a 1.
In the next square to the good put a 2.
In the next square to the quick put a 3.
In the next square to the quick put a 4.
In the next square to the bad put a 5.
In the next square to the slow put a 6.
In the next square to the bad put a 7.
In the next square to the quick put an 8.

In the starting square put a 1.
In the next square to the good put a 2.
In the next square to the quick put a 3.
In the next square to the bad put a 4.
In the next square to the bad put a 5.
In the next square to the slow put a 6.
In the next square to the slow put a 7.
In the next square to the good put an 8.

In the starting square put a 1.
In the next square to the bad put a 2.
In the next square to the bad put a 3.
In the next square to the quick put a 4.
In the next square to the good put a 5.
In the next square to the quick put a 6.
In the next square to the good put a 7.
In the next square to the slow put an 8.

In the starting square put a 1.
In the next square to the bad put a 2.
In the next square to the bad put a 3.
In the next square to the slow put a 4.
In the next square to the quick put a 5.
In the next square to the good put a 6.
In the next square to the good put a 7.
In the next square to the quick put an 8.

In the starting square put a 1.
In the next square to the bad put a 2.
In the next square to the quick put a 3.
In the next square to the quick put a 4.
In the next square to the good put a 5.
In the next square to the good put a 6.
In the next square to the slow put a 7.
In the next square to the bad put an 8.

6.3 Participant Information Sheet

The study was given ethical approval by the Psychology Research Ethics Committee of the School of Philosophy, Psychology and Language Sciences, University of Edinburgh. Participants were given and asked to sign the following information sheet before starting the experiment:

Psychology
SCHOOL *of* PHILOSOPHY, PSYCHOLOGY *and* LANGUAGE SCIENCES

The University of Edinburgh
7 George Square
Edinburgh EH8 9JZ

Telephone 0131 650 3440
or direct dial 0131 650
Fax 0131 650 3461
Email Psychology@ed.ac.uk

Information Sheet for Volunteers

Study title: The influence of visual secondary tasks on prospective memory in healthy adults

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

What is the purpose of the study?

The aim of this study is to investigate properties of prospective memory (the ability to remember to execute planned tasks) in a virtual multitasking setting.

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason.

What will happen to me if I take part?

If you decide to take part we will ask you to perform some computer based tests that look at your ability to multitask and your prospective memory. It is estimated that these tasks take around 1 hour to complete. If you need a break at any time between test parts you are free to do so.

What do I have to do?

During the interview, the tasks are in the form of computer tests. The instructions for each test would be explained to you beforehand. There are tests in which we would like to audio record your responses to test questions. This is so we do not need to write everything down immediately as you perform the task and we can score your performance later which saves time. You will be wearing a headset for this. We will ensure that these recordings will be stored on a password protected computer and they will be destroyed once your answers have been written down and scored.

What are the possible benefits of taking part?

There will be no direct benefit to you by taking part, and your individual results will not be revealed to you. However, we will make any future publications of the findings available to you. It is hoped that the research will result in a better understanding of the effect of healthy adult ageing on the ability to multitask.

Will my taking part in this study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential. Any information about you will have your name and address removed so that you cannot be recognised from it. You will be allocated an anonymous ID code during testing which will be used in place of your name on any future publications.

What will happen to the results of the research study?

The final results may be written up for publication in peer–reviewed journals. Talks and presentations may be made at meetings and conferences. In all cases, your name and personal details will not be identified.

Who is organising the research?

The study is being conducted by Professor Robert Logie in the Department of Psychology at University of Edinburgh.

Who has reviewed the study?

This study has been granted ethics approval by the Philosophy, Psychology and Language Sciences Research Ethics Committee.

Contact for further information

If you wish to ask anything further, please contact:

Mister Karl Kopiske: k.k.kopiske@sms.ed.ac.uk
Telephone: 07821 551 975

Dr Robert Logie: rlogie@staffmail.ed.ac.uk

Thank you for taking the time to read this information sheet. If you have understood the contents of this sheet and wish to take part, please complete the consent sheet on the next page. If you have any questions please feel free to ask them now.

CONSENT FORM - Confidential

Title of project: **The influence of visual secondary tasks on prospective memory in healthy adults**

Please initial box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without legal rights being affected.
3. I understand parts of the experiment will be audio recorded for the purpose of the study.
4. I understand that all information will be kept confidential.
5. I agree to take part in the above study.

Name of Participant	Date	Signature
Name of Person taking consent (if different from researcher)	Date	Signature
Researcher	Date	Signature

6.4 Raw Data

Raw data as used in the data table in R:

Subject ID	*MPT: Spatial Single*	*MPT: Spatial Dual*	*MPT: Nonsense Single*	*MPT: Nonsense Dual*	*MPT: Difference Single-Dual*	*Final EVET Single*	*Final EVET Dual*	*EVET: Difference Single-Dual(final)*	*Group*
1	0.771429	0.314286	0	0	0.457143	-3	7	-10	1
2	1	0.371429	0	0	0.628571	12	-1	13	2
3	0	0	0.642857	0.214286	0.428571	7	8	-1	3
4	0	0	0.914286	0.285714	0.628571	14	10	4	4
5	0.985714	0	0	0	0.985714	11	10	1	1
6	1	0.6	0	0	0.4	10	0	10	2
7	0	0	0.5	0.285714	0.214286	5	6	0	3
8	0	0	0.571429	0.057143	0.514286	NA	NA	NA	4
9	0.928571	0.485714	0	0	0.442857	3	5	-2	1
10	0.785714	0.257143	0	0	0.528571	0	0	0	2
11	0	0	0.528571	0.214286	0.314286	3	11	-8	3
12	0	0	0.542857	0.157143	0.385714	2	4	-2	4
13	0.857143	0.314286	0	0	0.542857	9	10	-1	1
14	0.928571	0.3	0	0	0.628571	10	2	8	2
15	0	0	0.828571	0	0.828571	9	16	-7	3
16	0	0	0.485714	0.257143	0.228571	12	-3	15	4
17	0.671429	0.171429	0	0	0.5	-2	2	-4	1
18	1	0.914286	0	0	0.085714	-1	0	-1	1
19	1	0.228571	0	0	0.771429	11	-1	12	2
20	0	0	0.657143	0.028571	0.628571	-1	4	-5	3

Subject ID	*MPT Type*	*t-score: MPT Difference*	*t-score: Final EVET Difference*	*Simple EVET Score*	*Simple EVET Score*	*Sequence*	*t-score: Simple EVET Difference*	*EVET: Simple - Final Score (single)*	*EVET: Simple - Final Score (dual)*
1	1	-5.10941	0.256606	4	8	1	0.881451	-7	-1
2	1	-4.61313	-1.07171	8	3	2	-1.42711	4	-4
3	2	-2.77109	0.31706	8	8	1	1.044466	-1	0
4	2	-2.29514	0.707287	8	8	2	1.044466	6	2
5	1	-7.83893	0.754722	8	8	1	0.881451	3	2
6	1	-2.62802	-0.90567	5	3	2	-1.42711	5	-3
7	2	-2.29514	-0.26828	6	6	1	0.087039	-1	0
8	2	-3.81818	NA	NA	NA	2	NA	NA	NA
9	1	-3.62057	-0.07547	5	4	1	-0.9654	-2	1
10	1	-5.60568	-0.90567	4	4	2	-0.9654	-4	-4
11	2	-2.77109	0.902401	8	8	1	1.044466	-5	3
12	2	-3.15185	-0.46339	3	4	2	-0.87039	-1	0
13	1	-5.10941	0.754722	8	6	1	-0.04197	1	4
14	1	-5.23347	-0.57359	7	6	2	-0.04197	3	-4
15	2	-4.19894	1.877969	8	8	1	1.044466	1	8
16	2	-2.48552	-1.82919	8	3	2	-1.3491	4	-6
17	1	-6.3501	-0.57359	5	5	1	-0.50369	-7	-3
18	1	0.101511	-0.90567	5	5	1	-0.50369	-6	-5
19	1	-5.85382	-1.07171	8	4	2	-0.9654	3	-5
20	2	-4.00856	-0.46339	2	7	1	0.565752	-3	-3

6.5 Raw Output for Analyses from R

6.5.1 ANOVA for Hypothesis 1

```
Analysis of Variance Table

Response: mtable5[, 12]
                           Df Sum Sq Mean Sq F value  Pr(>F)
mtable5[, 10]               1 1.1121  1.1121  1.7841 0.20156
mtable5[, 15]               1 4.2912  4.2912  6.8842 0.01917 *
mtable5[, 10]:mtable5[, 15]  1 0.0041  0.0041  0.0066 0.93648
Residuals                  15 9.3501  0.6233
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

6.5.2 ANOVA for Hypothesis 2

```
Analysis of Variance Table

Response: mtable5[, 11]
                           Df Sum Sq Mean Sq F value  Pr(>F)
mtable5[, 10]               1 13.091 13.0912  4.3552 0.05325 .
mtable5[, 15]               1  0.012  0.0118  0.0039 0.95076
mtable5[, 10]:mtable5[, 15]  1  0.199  0.1995  0.0664 0.79998
Residuals                  16 48.094  3.0059
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

6.5.3 ANOVA for Simple EVET Scores

```
Analysis of Variance Table

Response: mtable7[, 16]
                           Df Sum Sq Mean Sq F value  Pr(>F)
mtable7[, 10]               1 2.8767  2.8767  5.2590 0.03670 *
mtable7[, 15]               1 4.7441  4.7441  8.6727 0.01004 *
mtable7[, 10]:mtable7[, 15]  1 0.0565  0.0565  0.1033 0.75237
Residuals                  15 8.2052  0.5470
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```